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TRI-SERVICE PAVEMENTS WORKING GROUP (TSPWG) MANUAL

ALKALI-AGGREGATE REACTION IN PORTLAND CEMENT CONCRETE (PCC) AIRFIELD PAVEMENTS

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TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M)

ALKALI-AGGREGATE REACTION IN PORTLAND CEMENT CONCRETE (PCC) AIRFIELD PAVEMENTS

Indicate the preparing activity beside the service responsible for preparing the document.

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This TSPWG Manual supersedes Air Force Engineering Technical Letter (ETL) 06-2, *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements*, 9 February 2006.

FOREWORD

This Tri-Service Pavements Working Group Manual provides guidance on identification, maintenance, and avoidance of alkali-aggregate reaction problems in portland cement concrete (PCC) airfield pavements. It supplements guidance found in other Unified Facilities Criteria, Unified Facility Guide Specifications, Defense Logistics Agency Specifications, and service-specific publications. The information in this TSPWG Manual is referenced in technical publications found on the Whole Building Design Guide. It is not intended to take the place of service-specific doctrine, technical orders (TOs), field manuals, technical manuals, handbooks, Tactics, Techniques, and Procedures (TTPs), or contract specifications, but should be used along with these to help ensure pavements meet mission requirements.

All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the TSPWG Manual, the SOFA, the HNFA, and the BIA, as applicable.

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TRI-SERVICE PAVEMENTS WORKING GROUP MANUAL (TSPWG M) NEW SUMMARY SHEET

Document: TSPWG Manual 3-250-04.06-2, *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements.*

Superseding: ETL 06-2, *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements*, 9 February 2006.

Description: This manual provides specifications for construction of contingency airfields. It applies to DoD agencies and their contractors.

Reasons for Document:

This TSPWG Manual provides designers and maintenance personnel the latest on identification, maintenance, and avoidance of alkali-aggregate reaction problems in portland cement concrete (PCC) airfield pavements.

Impact: There is no cost impact. The following benefits should be realized:

- Supplemental information on the operation, maintenance and repair of pavements experiencing alkali-aggregate reaction problems will be available to all services.
- Maintenance and/or upgrading of this supplemental information will include inputs from all services.

Unification Issues

None

Note: Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this manual does not imply endorsement by the Department of Defense (DoD).

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND APPLICABILITY.

This manual provides guidance for identifying, maintaining, and avoiding alkali-aggregate reaction problems in portland cement concrete (PCC) airfield pavements. It includes information regarding the resurgence of destructive alkali-silica reaction (ASR) in PCC airfield pavements; briefly reviews the mechanism of the ASR reaction; explains how to identify ASR in the field; summarizes experience in trying to maintain pavements with ASR; and discusses available alternatives to avoid ASR in new pavements. Testing protocols are provided to identify potentially reactive aggregate, as well as required mitigation.

This manual applies to DoD airfield pavements.

Note: Alkali-carbonate reaction is rare and has not been observed in DoD pavements.

1-2 CAUTIONS.

Guidance in this manual reflects a consensus regarding best practices to minimize and mitigate ASR. Following this guidance will not necessarily prevent ASR, as knowledge in this area is evolving. Older standard texts, reports, and references may be out-of-date and no longer valid.

1-3 BACKGROUND.

The re-emergence of ASR as an airfield pavement problem with potential additional issues with alkali-carbonate reaction and potential destructive effects of anti-icing and deicing chemicals has greatly increased the complexity and sophistication of testing that must be conducted by the contractor under current military airfield procurement methods. These testing requirements potentially cause significant delays in the start of the project; it is prudent to recognize this and allow additional time at the start of the contract. This testing is costly and when required by UFC, UFGS, or other authoritative guidance cannot be waived. Concrete mixture proportion-ing for airfield pavements requires a sophisticated process to ensure proper constructability, durability, and strength. To assess the adequacy of bids for airfield paving work, ensure that the contractor is responsible for carrying out this critical task and ensure it is adequately addressed. The new requirements for testing to identify potentially reactive aggregates and mitigate ASR are complex, cumbersome, and expensive. However, the potential damage and maintenance costs of dealing with ASR in airfield pavements justify these precautions for new concrete.

1-3.1 Existing DoD specifications are intended primarily for contract work. Generally, they are too complex for contingency construction. The need to develop simple specifications that can be readily adopted by contingency construction units is apparent. Initial specifications developed for airfields have been revised and now include quality control (QC)/quality assurance (QA) procedures and checklists for identifying and correcting construction problems. These specifications were further reorganized and revised in 2008 to align the material requirements with current Unified Facilities Guide Specifications (UFGS) and to add unit price language to each specification.

1-3.2 In the last two decades, DoD has suffered destructive ASR to airfield pavements on multiple air bases within the continental United States (CONUS) and outside CONUS (OCONUS). Where this destructive reaction between the alkalis in the concrete and certain types of aggregate has occurred, the airfield pavement generally requires extensive and on-going maintenance and poses increased foreign object damage (FOD) hazard to aircraft.

ASR in concrete was first described in 1940. The military issued guidance for controlling ASR in airfield pavements based on research conducted in the 1940s and 1950s. However, by the mid-1990s, pavements built in accordance with that guidance were showing damage from ASR — in some cases in as little as five years after construction. In response to these problems, ad hoc modifications were made to guide specifications governing concrete airfield pavements. UFGS 32 13 14.13, *Concrete Paving for Airfields and Other Heavy-Duty Pavements*, is the latest specification limiting new ASR problems. There are active research programs underway on ASR in pavements through the Federal Aviation Administration- (FAA-) sponsored Innovative Pavement Research Foundation (IPRF) program, by state departments of transportation, and other organizations. As these efforts provide new information, guidance will be modified to reflect this new knowledge. It is important to recognize that the guidance in this manual represents the best current recommendations for dealing with ASR in pavements, but it is not the final answer.

1-3.3 Several factors have contributed to the re-emergence of ASR as a pavements problem.

a. Changes in portland cement manufacturing processes led to an increase in alkali content of commercially available conventional portland cement from an approximate average of about 0.4 percent in the past to around 1.2 percent today. This increase was partially driven by the increase in energy costs starting in the 1970s, which favored shifting from a wet-grind process to a dry-grind process, and partially by stricter modern air emission standards. portland cements that are specially manufactured to be designated as low alkali must have 0.60 percent or less alkali content (sodium oxide equivalent [Na2Oeq] as defined in American Society for Testing and Materials (ASTM) C150, Standard Specification for Portland Cement). However, previous research recognized that this limit was not completely effective — alkali contents between 0.45 and 0.60 percent may react, whereas contents of 0.40 percent or less rarely did. The 0.60 percent alkali limit represents a compromise between economic production and technical considerations. Today, modern low-alkali cements almost invariably crowd this 0.60 percent allowable upper limit for the same reasons the average alkali content of regular cements has increased. Use of low-alkali cements alone is not adequate to protect against ASR.

b. Aggregates that passed available tests for reactivity have reacted over long periods of time and have caused cracking and expansion in concrete.

c. Serious damage to concrete from alkali-aggregate reaction has occurred in places where it was previously unknown.

d. Certain slow-reacting aggregates have been identified that were not previously understood or recognized.

e. Modern concrete mixtures typically include a complex mix of other ingredients (e.g., admixtures, pozzolans) besides the traditional portland cement and aggregates that may impact these ASR reactions. Alkalis may be supplied by internal ingredients (e.g., portland cement, fly ash, admixture, aggregates, mix water) or external sources (e.g., deicing salts, ground water, seawater). At present there is no consensus on how to effectively set or even measure a limit on the combined alkali content from all sources (e.g., portland cement, fly ash, air entraining admixture). As air emission standards tighten, the alkalinity of products such as portland cement or fly ash will tend to rise.

f. Aggregates are increasingly scarce in many areas today, and there is often pressure to use aggregates from new sources or aggregates of marginal quality. These aggregates often have not been adequately assessed for potential reactivity.

g. As a matter of policy, the military has increasingly shifted responsibility for concrete and its constituents to the contractor and conducts relatively few independent tests on any of the cement, aggregates or other constituents used in concrete for military airfields. Previously, government laboratories performed all aggregate testing and approval, identified approved sources of aggregates, and developed the concrete mixture proportions for military airfields. Not all contractors and concrete producers have proven ready for this shift in responsibility. Previously, government laboratories had lengthy periods to carry out laboratory testing and approval of potential aggregate sources before construction bids were solicited. In contrast, the contractor now must carry out such assessments very rapidly in order to prepare bids and, if the successful bidder, avoid delaying construction.

h. Evidence exists that certain anti-icing and deicing chemicals used on airfield pavements accelerate ASR and hinder the effectiveness of some ASR mitigation methods.

i. Alkali-aggregate reactions are relatively slow, and it may take years or decades for symptoms to appear in the pavement. Consequently, it is practically impossible to hold the contractor responsible for placing such defective material. Correspondingly, there is little incentive for the contractor to take adequate measures to protect against alkali-aggregate reactions, since such measures tend to increase the construction and testing cost and make the contractor less competitive in a low-bid construction acquisition. This is a particular concern for design-build contracts that are becoming increasingly popular in the procurement of airfield pavements and many other facilities.

CHAPTER 2 WHAT IS ALKALI-AGGREGATE REACTION?

2-1 INTRODUCTION.

There are two types of recognized alkali-aggregate reaction: alkali-silica reaction (ASR); and the much rarer alkali-carbonate reaction. In each case, alkalis present in the concrete in the portland cement, fly ash, admixtures, aggregates, or other sources react with siliceous minerals in the fine or coarse aggregate (ASR) or with some dolomitic carbonate aggregates (alkali-carbonate reaction). This reaction forms a hydrophilic (water-loving) gel around the aggregate particles that absorbs water and causes internal expansive pressure in the concrete. Alkali-aggregate reaction can be harmless, or very destructive, with severe cracking and pop-outs that pose a severe FOD hazard to aircraft and concrete expansion that damages adjacent pavement, shoulders, and structures. Only ASR has been encountered and will be the focus of this manual. Three components are necessary for ASR to develop: reactive aggregates, alkalis, and water.

2-2 AGGREGATES.

2.2.1 Reactive aggregates have been identified in almost every state in the U.S. They are found widely around the world and are common in many areas of southwest Asia. In the continental United States, the following types of aggregates have reportedly caused destructive ASR reaction problems:

- <u>Atlantic Seaboard</u> (Maine to Georgia): Primarily metamorphic rocks such as gneiss, granite-gneiss, schist, quartzite, metagraywacke, metavolcanics, and chert.
- <u>Southern states</u> (Florida to Texas): Primarily chert and quartzite, with some opaline and chalcedonic carbonates and shales.
- <u>Midwest</u> (Ohio to Minnesota and Missouri): Opaline to chalcedonic carbonates, shales, and sandstones.
- <u>Great Plains</u> (North Dakota to Oklahoma, and Colorado): Opaline to chalcedonic carbonates, shales, and sandstones.
- <u>Basin and range</u> (Montana to Arizona): Glassy to cryptocrystalline rhyolite to andesite volcanics and chert.
- <u>Pacific Coast</u> (Washington to California): Glassy to cryptocrystalline rhyolite to andesite volcanics, chert, and opaline sedimentary rocks.

2.2.2 Aggregates throughout the U.S. and the world have been found to be reactive. No fine or coarse aggregate to be used in airfield pavement concrete can be assumed automatically to be non-reactive. Because the portland cement alkali contents have increased and modern concrete mixtures are increasingly complex, with a variety of admixtures and pozzolans, past experience with an aggregate is not sufficient to judge if it will be reactive or not. An aggregate that was not reactive in the past may react with the higher alkali content typical of modern cements and concrete mixtures. The long ASR reaction time of years -- or even decades -- further complicates trying to use past experience for acceptance of an aggregate as non-reacting. Consequently, all aggregates to be used in PCC airfield pavements must be tested as described in this manual.

2-3 LOW-ALKALI CEMENTS.

Low-alkali cements were the traditional defense against ASR when reactive aggregates were used in concrete mixtures. However, airfield concrete mixtures with low-alkali cements have recently suffered destructive ASR reactions. Simply specifying low-alkali cement alone cannot be assumed to be adequate protection for all aggregates.

2-4 WATER.

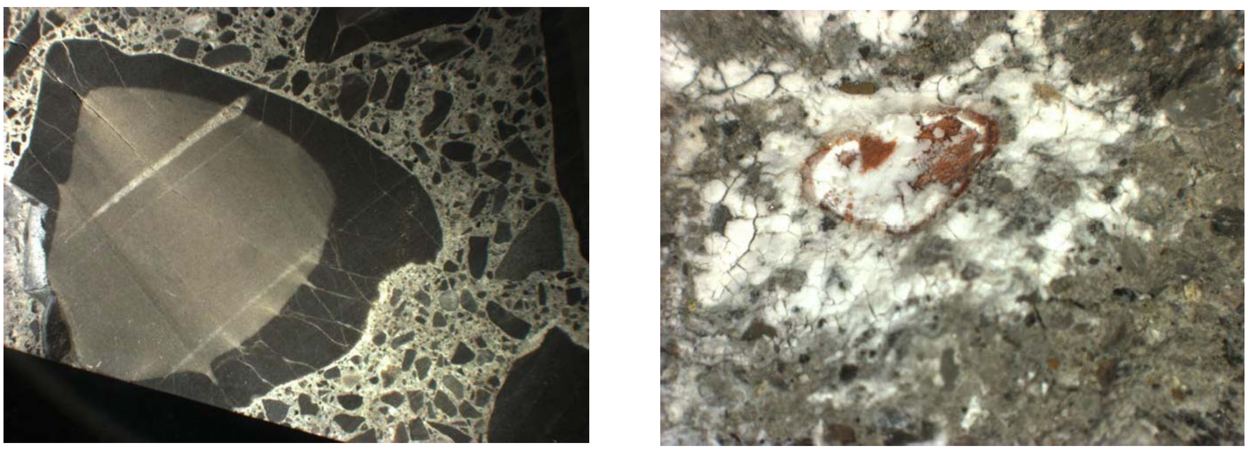
Even in arid regions, adequate water is present to support ASR reactions in concrete pavements. Water vapor from under the pavement is often sufficient to maintain ASR reactions, and attempts to seal the pavement to prevent water entry have not been successful.

CHAPTER 3 FIELD SYMPTOMS OF ASR

3-1 INTRODUCTION.

The ASR gel (Figure 1) around or within the reacting aggregates absorbs water and increases in volume. This can lead to (1) cracking as the tensile strength of the concrete is exceeded; (2) surface pop-outs from internal compressive forces caused by gel growth; and (3) overall expansion of the mass of concrete.

Figure 1 Examples of Alkali-Aggregate Gel



It may appear as a dark rim around an aggregate particle (left), or as a light-colored deposit on or within the aggregate or in the surrounding matrix (right). Note cracks caused by the expansion of the gel in the aggregates and paste.

3-2 CRACKING.

There are many causes of cracking in concrete, ranging from induced load to poor slab geometry to premature loss of water. Concrete cracking caused by ASR tends to develop some characteristic patterns that help identify it. As the reacting aggregates increase in volume within the concrete matrix, the accumulating concrete expansion exceeds the strength of the concrete. This develops a characteristic map cracking such as seen in Figures 2 through 4. In runways, taxiways, and similar geometries, the mass of concrete along the feature's length provides restraint in the longitudinal direction so the greatest concrete expansion tends to be laterally. This forms predominately longitudinal cracking such as seen in Figures 2 and 3. Where there is no particular preferred direction of restraint, as in a ramp, the cracking pattern will be more random (Figure 4). The presence of reinforcing steel may also lead to restraint and influence crack patterns.

Figure 2 ASR-induced Cracking on Taxiway, Holloman AFB

Note cracks are preferentially longitudinal and continue across transverse joints.

Figure 3 ASR-induced Cracking in Taxiway at Channel Island ANG Facility

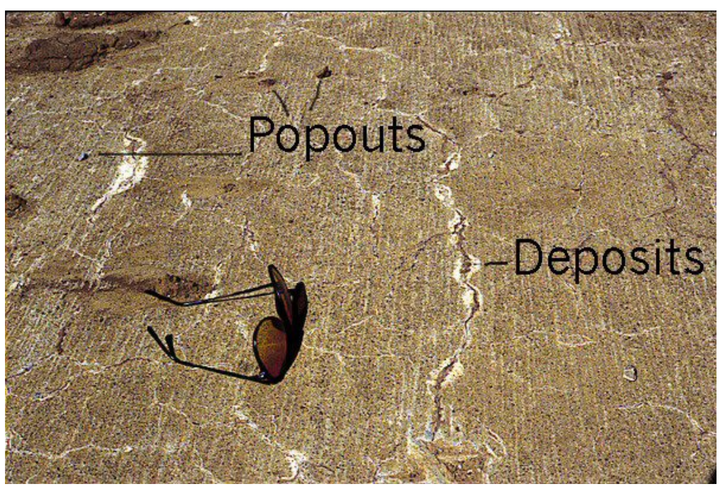
Note cracks are preferentially longitudinal and continue across transverse joints.

Figure 4 ASR-induced Cracking in Ramp at Tinker AFB

Note cracks are random (without the preferential longitudinal orientation seen in Figures 2 and 3) and continue across joints.

ASR-induced cracks may contain deposits that range from white to transparent, and may be waxy to hard (Figure 5). These deposits may be ASR gel, or they may be other deposits from totally different sources. It is impossible to identify the material without a chemical analysis. Neither the presence nor the absence of such visible deposits can be considered an indication that ASR is present.

Figure 5 Popouts and Deposits at Cracks, Tinker AFB



3-2.1 Non-ASR Causes of Cracking.

It is important to recognize the differences in cracking caused by ASR and other totally different sources. Cracking from ASR can easily be confused with plastic shrinkage cracking and D-cracking. Plastic shrinkage cracking appears early and is often (although not always) relatively shallow. ASR cracking takes years to develop, and occurs throughout the reacting concrete. D-cracking tends to parallel the joints in a distinctive C-shape, whereas ASR cracking crosses joints.

3-2.1.1 Plastic Shrinkage.

Plastic shrinkage cracking often forms polygonal map cracking similar to the ASR cracking in Figure 4. It is a construction defect caused by excessive moisture loss from the concrete at early stages. Plastic shrinkage cracking forms immediately after construction and is usually clearly noticeable within a few days or weeks. On the other hand, ASR cracking will not appear for a number of years. Plastic shrinkage cracking is often a relatively minor surface blemish and extends only a fraction of an inch below the surface, although in extreme cases it can be deeper. In contrast, ASR cracking is prevalent throughout the concrete mass.

3-2.1.2 Durability ("D")-cracking.

D-cracking is caused by freezing-and-thawing deterioration of certain vulnerable coarse aggregates. The cracking forms where moisture is most abundant in the slab — adjacent to joints and on the bottom of the slab. As cracking progresses, more water can enter the pavement and deterioration expands further into the slab. D-cracking tends to form cracks parallel to the joints, as illustrated in Figure 6. In Figure 2, the ASR cracks run parallel to the longitudinal joint on the left side of the photo, and continue across the transverse joint. In D-cracking, additional cracking would have formed parallel to the transverse joint, and the result would have been the characteristic roughly C-shaped cracking that follows the joint patterns. D-cracking is most commonly encountered with certain limestone aggregates, but may also be seen in other predominantly sedimentary rocks.

Figure 6 D-cracking at Grissom AFB

Note general C-shape of cracks that are roughly asymptotic to joints and do not cross transverse joints, as illustrated by Figures 2 and 3.

3-3 POP-OUTS.

As the compressive forces within the concrete increase, individual aggregate particles may be dislodged. These particles, or “pop-outs”, then pose a potential aircraft FOD hazard. Figure 5 shows an example of pop-out fragments from ASR. Pop-outs also develop in concrete that has aggregates such as chert or shale that are vulnerable to freezing or contain other unsound particles.

3-4 EXPANSION.

The internal expansive forces increase as the ASR gel absorbs water, the concrete volume increases, and the concrete in the field literally grows. This leads to differential movements, closing of expansion joints, damage to adjacent structures, spalling at joints, and similar problems. In an extreme example at Andrews AFB, Maryland, the expansive forces were severe enough to cause an entire lane of parking ramp slabs to fail and tent up (similar to concrete pavement blowups occasionally observed on roads) in one morning. Figure 7 shows an example of differential movement between two slabs caused by ASR expansion in the concrete. Such movement on airfields may be a few inches or a foot or more. In Figure 8, the asphalt shoulder has been upheaved by the ASR expansion in the adjoining concrete. Structures such as trench drains within the pavement may suffer serious misalignment or breakage and the compressive forces at the joint may cause severe spalling. In Figure 9, note that in the ASR-induced cracking in the concrete to the left of the drain, the expansion joint between the concrete and trench wall is squeezed closed; spalling is developing in the concrete because of high compressive stresses from the expanding concrete, and the trench grate is tightly jammed as the trench walls have been forced inward. A forklift will be needed to pull the trench drain grate free.

Any structures adjacent to pavement undergoing ASR volume expansion are vulnerable to damage. Expansion joints normally used to isolate the structures from the normal thermal and moisture movements of the concrete pavement will be unable to cope with the magnitudes of movement encountered in ASR-driven volume expansions. Figure 10 shows a terminal building column pushed out of alignment by ASR expansion in the adjacent pavement. The building had to be abandoned.

Figure 7 Misalignment of Slabs Caused by Differential ASR Expansion, Kirtland AFB

Figure 8 Asphalt Shoulder Heaving Caused by ASR Expansion in Adjacent Concrete at Seymour-Johnson AFB

Figure 9 Trench Drain Damage from ASR Expansion, Holloman AFB

Figure 10 Building Column Pushed Out of Alignment by ASR Volume Expansion in Adjacent Concrete Pavement, Albuquerque, NM

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CHAPTER 4 IDENTIFYING ASR

4-1 FIELD OBSERVATION.

Inspect the concrete for symptoms of ASR described in Chapter 5. Excessive concrete expansion causing upheaval and damage to adjacent structures is strongly suggestive of ASR. Look for upheaved shoulders, buckled pavements, expansion joints that are squeezed shut, damaged utility trenches and other structures, and development of spalling from excessive compressive stresses. The internal volumetric expansions will generally cause cracking that is relatively distinctive, as discussed in paragraph 3.2. Be careful not to confuse plastic shrinkage cracking and D-cracking with ASR cracking. Finally, pop-outs and deposits at cracks may be detected. These may be caused by factors other than ASR, so they are only somewhat corroborative if the expansion and cracking symptoms are also present. Field observations can only verify that symptoms of ASR are present. Only laboratory examination can definitively determine whether ASR is present.

4-2 LABORATORY EXAMINATION.

Laboratory examination by an experienced petrographer is the most reliable method of determining whether ASR reactions are occurring in concrete. Petrography is the field of geology dealing with identification and classification of rocks and minerals. Concrete petrography is a specialized subfield using many of the same techniques as classic petrography, but including detailed understanding of concrete with techniques to assess various physical and chemical phenomena unique to the concrete environment. The American Society of Testing and Materials requires the petrographer doing petrographic examinations for concrete (ASTM C295, *Standard Guide for Petrographic Examination of Aggregates for Concrete*, and ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete*) to have five years' experience specifically in concrete petrography. Ensure credentials are verified for all petrographic work done. The quality and usefulness of any petrographic examination is entirely dependent on the skills of the petrogropher.

Core samples are obtained from the concrete and sent for examination to a laboratory qualified to conduct the examination under ASTM C856. Such examinations are relatively expensive, and the number of laboratories capable of providing such services is limited. The Concrete Branch of the Geotechnical and Structures Laboratory of the U.S. Army Engineer Research and Development Center (ERDC) at the Waterways Experiment Station, Vicksburg, Mississippi, maintains concrete laboratory test facilities and personnel capable of conducting such examinations on a cost-reimbursable basis. Petrographic examination by the ERDC Concrete Branch is the preferred diagnostic resource for ASR.

4-3 DIAGNOSTIC STAINING SYSTEMS.

4-3.1 Uranyl-Acetate Solution.

If a prepared concrete surface is treated with uranyl-acetate solution and exposed to ultraviolet light, the ASR gel appears as bright yellow or green. The test requires experienced technicians and proper interpretation, but does not distinguish between the harmless presence of ASR gel and destructive damage developing from ASR reactions. In addition, fluorescence may be caused by sources other than ASR gel. Consequently, this is an ancillary test and cannot be relied upon to diagnose ASR. The uranyl-acetate solution contains a low-dosage radioactive compound and may be subject to safety and disposal restrictions.

4-3.2 Sodium Cobaltinitrite and Rodamine Solutions.

Sodium cobaltinitrite reacts with lithium in the ASR gel to form a yellow precipitate, while some rodamine compounds react with calcium-rich ASR gels to form a pinkish precipitate. This is a patented process, and a commercial kit (*ASR Detect*) based on this technology is marketed by James Instruments, Inc., 3727 N. Kedzie Avenue, Chicago, Illinois, 60618–4545. The technology has the potential to serve as a rapid field screening or as an aid in a more detailed petrographic examination. The manufacturer’s claims for this proprietary commercial kit have not been independently verified for DoD use.

CHAPTER 5 MAINTAINING PAVEMENTS WITH ASR

5-1 INTRODUCTION.

At present, technology does not exist that can stop ASR reactions that are occurring in airfield pavements. The reactive constituents are already in the pavement, and moisture to fuel the destructive expansion is readily available to pavements, even in arid regions. The only certain method of dealing with destructive ASR-affected pavements is to remove the affected concrete and replace it with new concrete that is not susceptible to ASR. Maintenance should address ASR symptoms.

If the reactions are relatively slow and destructive effects are minor, maintenance may be all that is needed to get the full design life out of the pavement. Increased sweeping efforts will be required as pop-outs develop and as ASR cracking and expansion lead to spalling and loose fragments.

5-2 PATCHING.

5.2.1 Partial-depth and full-depth patches are used to temporarily fix the areas that become unacceptable. Figure 2 shows an example where ASR cracking has progressed to the point where FOD debris will soon be generated, and patching should be considered in the near future. Patching is simply a stop-gap measure to reduce FOD hazards in the immediate future, as deterioration will continue in the surrounding pavement in coming years.

5.2.2 Follow conventional DoD directives for airfield pavement patching of ASR-affected pavements. Either conventional PCC or proprietary patching materials can be used. Follow good patching practices; e.g., saw cut around repair area, remove to sound concrete, meticulously clean the repair surface, properly mix, place, and cure the patching material, and reestablish all joints. The ASR reactions will continue in the concrete around the patch (and may even be enhanced by addition of new alkalis in the patching materials) and deterioration will continue in the original concrete. It may be particularly difficult to patch some ASR pavements because it may be hard to locate sound concrete. In such cases, full-depth patches are necessary.

5.2.3 In arid regions, the evaporative process concentrates alkalis in the upper portion of the pavement. This accelerates damage in the upper region of the pavement, but sound concrete may exist below the worst-damaged concrete. At Holloman AFB, ASR gel coated all internal cracks, fissures, and voids, and was present throughout the upper region of the concrete (Figure 11). This gel appeared as a white haze on all repair surfaces and proved impossible to remove by washing, brushing, water-blasting, and sandblasting. Because of this, it was almost impossible to get a good bond with patching materials. Failure rates for some patching efforts exceeded 80 percent. Recent patches have been going deeper (minimum 6 inches [152 millimeters]), and this has helped. While patching ASR-damaged pavements can correct existing surface deficiencies, the patching conditions are difficult, and on-going ASR deterioration will cause continuing future problems.

Figure 11 ASR Gel Used at Holloman AFB

5-3 OVERLAYS.

Conventional overlays are candidate repair and rehabilitation methods for pavements undergoing destructive ASR reaction. The ASR reaction in concrete will continue as long as alkalis, reactive minerals, and water are present. Once any of these is consumed, the reaction typically ends and the material stabilizes. At present, we do not have the technical understanding to reliably predict when the alkali-silica reaction will end or even ascertain for a specific concrete if it has ended. Consequently, expansion and deterioration of the original pavement will continue and may significantly reduce the effective life of the overlay. Fully bonded concrete overlays could be considered as a means of mitigating surface problems for several years and perhaps longer, as in the case of Pease AFB[1]. Both partially bonded and unbonded concrete overlays typically improve the situation, but the potential increased interaction between the ASR-affected lower pavement and a partially bonded overlay suggests an unbonded overlay may have better long-term success. Flexible overlays are possible as a stop-gap to correct serious surface deterioration, but only as a temporary measure. Expansion in the underlying ASR-affected pavement below flexible or rigid overlays can be expected to

[1] In the 1980s, Pease AFB, New Hampshire, used thin bonded overlays to reduce FOD hazards on pavements deteriorating from ASR, and these patches largely remain functional today. Selected slabs were milled 3 inches (76 millimeters) and a 3-inch (76-millimeter) -thick fully bonded overlay was placed. Pease AFB had much thicker pavements than required at the time because of a mission change, so the overlays were applied purely to correct surface FOD problems. As expected, underlying longitudinal cracks (originally from over-vibration by vibrators during construction and unrelated to ASR) reflected through the overlay rapidly, but FOD debris generation was significantly reduced.

continue to damage adjacent pavements and structures and the overlay may also be affected.

Cracking and seating or rubblizing the original pavement and then overlaying with asphalt offers uncertain alternatives. The cracking and seating or rubblizing allow easier penetration of water into the concrete that would speed the ASR reaction. However, it also generates some additional void space in the cracks that may absorb some expansion. The on-going ASR reaction within the individual fragments of concrete may cause further breakdown and change in properties of the cracked and seated or rubblized concrete. There is insufficient experience with overlays for ASR-damaged pavements to provide sound advice at this time. For additional information on rubblizing concrete, see TSPWG 3-250-07.07-6, *Risk Assessment Procedure for Recycling Portland Cement Concrete (PCC) Suffering from Alkali-Silica Reaction (ASR) in Airfield Pavement Structures.*

5-4 EXPANSION JOINTS.

Expansion is particularly difficult to deal with as it causes damage to adjacent and imbedded structures and pavements. Expansion joints can be cut into the pavement to absorb the expansion, but these will eventually close and have to be recut. At Seymour-Johnson AFB, 1.5-inch (38-millimeter) -wide expansion joints have closed in about two years, and 4-inch (101-millimeter) -wide joints have closed to 1 inch (25 millimeters) in five to ten years. In extreme cases — such as Ft. Campbell Army Airfield where expansion joints were being closed in a matter of months — an entire row of concrete slabs was removed and replaced with a flexible pavement. The repair to this flexible pavement is then arguably easier and more rapid than repairing damaged PCC. At Travis AFB, California, utility cuts in a ramp undergoing ASR were put under such pressure over the years that the concrete in the utility cuts was crushed. Saw cuts at joints to facilitate removing this pavement during ramp rehabilitation saw slabs dropping as much as 0.75 inch (19 millimeters) when cut. The compressive forces from ASR expansion in this ramp were sufficient to bow the slabs upward.

There is no good solution to dealing with expansion. Try cutting expansion joints first, then recutting them, possibly wider, as they close. If this fails, try removing a lane of slabs and replacing them with asphalt concrete, as was done at Ft. Campbell Army Airfield, Kentucky. Neither of these are satisfactory solutions, but ignoring the expansion can lead to damage to adjacent structures and pavements, crushing of embedded structures, and possible buckling of slabs (as occurred at Andrews AFB [paragraph 3.4] and was probably imminent at Travis AFB’s ramp).

5-5 SURFACE TREATMENT.

Attempts to dry the concrete or seal out moisture to impede continued ASR expansion show little promise for pavements because of the exposed environment of concrete pavement and ready availability of water vapor under the pavement.

5-5.1 Sealers.

5-5.1.1 Methyl Methacrylate.

Surface treatment of the concrete with very-low-viscosity methyl methacrylate was tried at Seymour-Johnson AFB, North Carolina. This low-viscosity material soaks into the upper surface of the concrete and into cracks to make the surface more impervious and strengthen the concrete to reduce spalling and raveling debris. The treatment is expensive, and after eight years, there was no noticeable difference in treated and untreated areas. It is not recommended for use. Treatment with other more economical concrete sealers such as silanes or siloxanes should not be attempted, as the surface-sealing approach using methyl methacrylate proved ineffective.

5-5.1.2 Lithium Salts.

There is potential for topical solutions of lithium salts to reduce surface compressive forces and perhaps reduce FOD debris generation. Significant penetration into the concrete by the lithium salts is highly unlikely. It is most likely to have benefit for mitigating shallow surface problems and is unlikely to affect deeper reactions and large-scale volume changes in the pavement. Repeat treatments may be needed, and there has been some work to encourage deeper penetration into the concrete using vacuum impregnation or electrochemical methods. Tests indicate these salts are not corrosive for aircraft. The technique has been tried on several highways, but results are inconclusive at present. Details of field trials on several highway projects may be found in FHWA Publication No. RD-03-047, *Guidelines for the Use of Lithium to Mitigate or Prevent Alkali-Silica Reaction (ASR)*. Topical application of lithium salts for ASR mitigation should be considered an experimental technology.

5-6 RECYCLING CONCRETE.

If considering recycling concrete undergoing ASR reactions within the airfield pavement structure, see TSPWG 3-250-07.07-6.

CHAPTER 6 ASR IN NEW CONSTRUCTION

6-1 INTRODUCTION.

The preference is to build airfield pavements with non-reactive aggregates, and a potentially reactive aggregate would ideally be replaced with a non-reactive one. This is not always possible. Non-reactive aggregates may be economically unavailable, or delays in finding, testing, procuring, and transporting non-reactive aggregates for a specific project may cause unacceptable delays to the construction.

There is no consensus in the technical community regarding how to identify ASR-susceptible aggregates or how new concrete mixtures should be proportioned and tested to prevent ASR in the field. Essentially, those laboratory tests that do the best job evaluating alkali-silica-susceptible concretes and mitigation methods take a year or more to run, which is not compatible with construction schedules. To get timelier results, other tests employ accelerated testing conditions that are difficult to relate to field conditions. Similarly, the important factors for determining the effect of total alkalis from all sources and effectiveness of countermeasures remain open to discussion. There is no perfect test, and our understanding of the complexities of the chemical reactions is imperfect. Research is actively being pursued by a number of organizations. Guidance must be based on results of this ongoing research as it becomes available and on field experience. In the interim, all concrete airfield pavements will adhere to the following:

- All concrete aggregates will be tested in accordance with ASTM C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*, to determine if they are potentially reactive or non-reactive.
- The preferred approach is to build airfield pavements with non-reactive aggregates, especially if deicing and anti-icing chemicals are used on the pavements — but this is not always feasible.
- If a potentially reactive aggregate is used in an airfield pavement, then a low-alkali cement is mandatory. Also use active mitigation methods. The effectiveness of the selected mitigation method and the amount needed are revealed by testing in accordance with ASTM C1567, *Standard Test Method for Determining the Potential for Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar Bar Method)*.

Actual implementation of this approach in accordance with DoD concrete airfield pavement guide specification UFGS 32 13 14.13 is more complicated (reference paragraphs 6.2 through 6.2.1).

6-2 TESTING TO IDENTIFY POTENTIALLY REACTIVE AGGREGATES.

Test all aggregates in accordance with ASTM C1260. If expansion exceeds 0.08 percent after soaking 28 days in a sodium hydroxide solution, the aggregate is presumed to be potentially reactive. Test each aggregate source separately, and also as a combined gradation representative of the contractor's proposed proportions for various aggregates in the concrete mixture.

All aggregate sources must be tested for ASR reactivity. Acceptance based on past performance is not allowed. The cement chemistry and concrete mixtures have significantly changed in recent decades and ASR reactions may take a decade or more to appear. The reliability of any assessment of past performance that must match evolving cement and concrete mixture chemistry to aggregate properties (that may not be consistent within a deposit), age, and exposure conditions, is problematic. A qualified concrete petrographer may assist in interpreting the significance and limitations of ASTM C1260 testing on any particular aggregate.

6.2.1 ASTM C1260 uses a mortar bar composed of one part cement to 2.25 parts aggregate with particles between the No. 4 and No. 50 sieves (coarse aggregates have to be crushed to provide this material), and a water-to-cement ratio of 0.47. After two days of curing, initial length measurements of the bar are taken and the mortar bars are placed in 1-normal sodium hydroxide solution at 176 °F (80 °C) for 28 days. Length measurements are periodically made, and if at the end of the 28 days' soaking in sodium hydroxide (30 days after casting) the length has increased by more than 0.08 percent, the aggregate is considered potentially reactive.

6.2.1.1 ASTM C1260 is reasonably rapid and provides usable results. However, it may exclude some aggregates that will not react in the field and may include some that will. The DoD allowable expansion limit of 0.08 percent or less in UFGS 32 13 14.13 is more stringent than the criterion of less than 0.10 percent expansion in some specifications. This is not overly conservative -- the 0.08 limit is required to control cracking in relatively thick and extensive (large area) airfield pavements where smaller volumetric changes from ASR may cause distress that would not be a problem for thinner and smaller structures. In addition, it is unclear whether acceleration of ASR reaction during testing by applying elevated temperatures and high chemical concentrations adequately forecasts behavior of critical airfield pavements that may be in use for 30, 40, or 50-plus years. Testing in accordance with ASTM C1260 and applying the UFGS expansion limit is the best compromise of accuracy and timeliness compatible with current construction practices.

6.2.1.2 ASTM C1260 mortar bars are soaked in a sodium hydroxide solution so the alkali content of the cement used in the test probably has at most a minor effect. UFGS 32 13 14.13 requires testing the combined grading, which is not required under ASTM C1260.

6.2.2 ASTM C1293, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*, is typically the preferred test method for identifying ASR-reactive aggregates. This test measures length change in a concrete prism made with high-alkali cement and stored at high humidity at 100 °F (38 °C), and requires at least a year to run. This length of testing is incompatible with modern construction procurement processes. UFGS 32 13 14.13 does not reference the test, but if results of ASTM C1293 testing are available, they are superior to ASTM C1260 for identifying reactive aggregates. While this is generally accepted as the best available test, even when run for two years, there is still uncertainty about its ability to predict behavior for large-volume airfield pavements during long service lives.

6-3 TESTING OF REACTIVE AGGREGATE AND MITIGATION MATERIALS.

If a potentially reactive aggregate will be used in concrete airfield pavements, use of a low-alkali cement is mandatory, and additional active mitigation measures are required. The effectiveness of the mitigation is determined through testing; simply using a prescribed formula (e.g., 25 percent Class F fly ash) is not adequate for airfield pavements. Chemical compositions of cements, fly ashes, ground granulated blast-furnace slags, and aggregates all vary individually. As a result, there is no universal formula for how much fly ash or slag to use in a concrete mixture. For the same reason, use the actual proposed project materials for testing. Determine the proportion of the mitigating material needed individually with acceptable results from appropriate testing.

Newly-constructed concrete airfield pavements that use potentially reactive aggregates must:

- Contain only low-alkali cement.
- Contain only Class F fly ash, ground granulated blast-furnace slag, and lithium admixtures as mitigation materials.
- Contain a percentage of fly ash or slag in the concrete mixture that reduces the expansion of the mortar-bar specimen to 0.08 percent or less after 28 days' soaking (30 days after casting) when tested in accordance with ASTM C1567.
- Use reactive aggregate from sources that are individually tested, and the selected mitigation material and amount of mitigating agent must reduce expansion to 0.08 percent or less after 28 days' soaking (30 days after casting) for each aggregate source when tested in accordance with ASTM C1567.

6-3.2 UFGS 32 13 14.13.

UFGS 32 13 14.13 (November 2017) requirements for testing and assessing mitigation results are current for military projects. This UFGS is updated on a 3-year cycle. Check the Whole Building Design Guide (http://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs/ufgs-32-13-14-13) for the most up-to-date version.

6-3.3 ASTM C1567.

ASTM C1567 is a modification of ASTM C1260 (paragraph 6.2.1) and is designed to assess the ability of pozzolans and ground granulated blast-furnace slag to control destructive internal expansions due to alkali-silica reaction in aggregates intended for use in concrete. It is an imperfect test, but represents the best compromise of technical accuracy and speed of testing available today. The test must be run using the contractor's proposed low-alkali cement, mitigating additive (e.g., fly ash, Class N pozzolan, ground granulated blast-furnace slag) in the proportions proposed by the contractor for his mixture. If length change after 28 days of soaking (30 days after casting) is equal to or less than 0.08 percent, the countermeasure is considered adequate; if the expansion is greater than 0.08 percent, use more of the proposed additive, alternate aggregate sources, or alternate countermeasures and test. ASTM C1567 mortar bars are soaked in a sodium hydroxide solution so the alkali content of the cement used in the test probably has at most a minor effect. This test is valid only for the specific combinations of pozzolan, slag, and reactive aggregates tested. It is not valid for tests of cements and aggregates only (i.e., no pozzolans and/or slag). This test potentially underestimates the expansion of cementitious systems if the pozzolans have greater than 4.0 percent sodium oxide equivalent. Such materials are best evaluated with ASTM C1293.

ASTM C1567 is not effective for assessing lithium admixtures. These admixtures tend to leach out in the artificially high alkalinity of the test and provide an invalid assessment of the effectiveness of lithium. Lithium admixtures appear to be highly effective in countering ASR, but may significantly increase the concrete mixture costs. They are often most economical when used with other mitigation materials.

6-3.4 ASTM C1293.

ASTM C1293 is the preferred test method for assessing effectiveness of ASR-mitigating materials. However, the recommended test period for evaluating the mitigation effectiveness of supplementary cementitious materials such as fly ash is two years. This is incompatible with current construction procurement processes. UFGS 32 13 14.13 does not reference this test, but if results of ASTM C1293 testing are available, they would be superior to ASTM C1567 for assessing effectiveness of fly ash, natural pozzolans, etc., for mitigation of ASR.

6-4 MITIGATION MATERIALS (COUNTERMEASURES).

6-4.1 Pozzolans.

Fly ash has been the most common countermeasure used, and 25 to 30 percent fly ash replacement for portland cement has frequently proven effective. Class F fly ash does better than Class C fly ash, and low calcium oxide (CaO) Class F fly ash does better than higher CaO content fly ashes. There is less experience with the natural Class N pozzolans on military projects. UFGS 32 13 14.13 allows use of Class F or N pozzolans to mitigate ASR and limits the CaO content of Class F fly ash to 8 percent. This lower-limit Class F fly ash is not always available. In general, it is best to use the lowest CaO content Class F fly ash that is readily available. Some suggested guidance for chemical composition of fly ash and suggested minimum fly ash content based on Canadian recommendations is shown in Table 1. The guidance provided in Table 1 is offered to provide interim suggestions if higher than desired CaO fly ashes must be used.

Table 1 Suggested Minimum Fly Ash Replacement Based on Chemical Composition and Canadian Recommendations

Fly Ash		Suggested Minimum Cement Replacement by Fly Ash, Percent by Mass
Alkali Content, Percent Na_2O_{eq}	CaO Content, Percent	
< 3%	< 8%	25%
	8 to 20%	30%
	> 20%	Not recommended
3–4.5%	< 8%	30%
	8 to 20%	35%
	> 20%	Not recommended
> 4.5%	Any	Consult AFCEC Pavements SME

Note: The proposed fly ash and final dosage rate must pass ASTM C1567, but if the CaO content of 8 percent is not met, the minimum fly ash contents in Table 1 may be desirable, even if a lower fly ash content passes ASTM C1567.

6-4.2 Ground Granulated Blast-Furnace Slag.

This product is increasingly available in some sections of the U.S. Generally, it will require a higher proportion replacement of the portland cement than fly ash -- typically 40 to 50 percent replacement. UFGS 32 13 14.13 allows use of this material to counter ASR.

6-4.3 Silica Fume.

This material can be effective in countering ASR, but introduces some other complexities in the batching, mixing, and pavement construction process. It typically requires at least 7 percent by cement mass to be effective for ASR mitigation. It requires less material than either fly ash or ground granulated blast-furnace slag. Silica fume is not listed in UFGS 32 13 14.13 as an acceptable ASR mitigation method. However, in the Middle East and other areas where fly ash and ground granulated blast-furnace slag are not readily available and ASR is a common problem, silica fume has been used on several military paving projects to help provide ASR resistance.

6-5 DEICING AND ANTI-ICING CHEMICALS.

6-5.1 Innovative Pavement Research Foundation (IPRF) Research.

Research by the Innovative Pavement Research Foundation (IPRF) at Clemson University found that deicing and anti-icing chemicals (potassium acetate, sodium acetate, potassium formate, and sodium formate) can cause increased expansion in ASR-susceptible aggregate and may trigger it in aggregates that previously did not show signs of ASR. Observation of distress associated with use of deicing and anti-icing chemicals at civil airports corroborates the initial findings of the Clemson laboratory work. (Reference IPRF-01-G-002-04-8, *Mitigation of ASR in Presence of Pavement Deicing Chemicals*.) Military bases that use these deicing and anti-icing chemicals could compound an existing ASR problem if they have one, and will have to take extra precautions if they plan new construction with ASR-reactive aggregates.

6-5.2 Interim Guidance for Testing.

Use Table 2 to determine if further specialized testing is required to determine whether additional mitigation may be needed to cope with exposure to anti-icing and deicing chemicals.

Table 2 Suggested Testing Requirements for New Concrete to be Exposed to Anti-Icing or Deicing Chemicals and Using Aggregate Sources Previously Used on the Airfield Pavements

	Existing Pavements Have ASR		Existing Pavements Do Not Have ASR	
Have anti-icing and/or deicing chemicals been used in the past?	Yes	No	Yes	No
ASTM C1260 shows the aggregate proposed for use is:				
Potentially reactive	A	A	C	B
Non-reactive	A	B	D	C

A High risk of increased ASR if anti-icing and deicing chemicals used; additional testing recommended.
B Moderate risk of increased ASR if anti-icing and deicing chemicals used; additional testing desirable.
C Little risk of increased ASR if anti-icing and deicing chemicals used; additional testing not recommended.
D Negligible risk of increased ASR if anti-icing and deicing chemicals used; additional testing not recommended.

Note: If the aggregate source is new and was never previously used for concrete pavements on the base, past history of exposure to deicing chemicals and development of ASR are of no help. For new aggregate sources, if the aggregate tests as potentially reactive it should be treated as case A, and if non-reactive it should be treated as case B.

6.5.2.1 The additional testing in Table 2 is the IPRF interim test protocol. This is essentially the ASTM C1260 test, but samples are soaked for 28 days in the specific anti-icing or deicing chemicals to which the concrete will be exposed, rather than sodium hydroxide. Acceptable results are less than 0.10 percent expansion after 28 days' soaking. For aggregates that test as potentially reactive by ASTM C1260, the mitigating agent and dosage to be used in the concrete pavement must pass the interim test protocol for each anti-icing or deicing agent that may be used at the base and it must also pass ASTM C1567 as outlined in paragraph 6.2.2. If the aggregate is non-reactive, it is only required to pass the IPRF interim test protocol.

6.5.2.2 The IPRF interim test protocol with anti-icing and deicing chemicals may increase the amount of fly ash or ground granulated blast-furnace slag needed to mitigate ASR above that found in ASTM C1567. The CaO content of fly ashes normally has a major impact on expansion in this test. If a specific fly ash is having trouble passing the test, changing to a lower CaO content fly ash may help.

6.5.2.3 Topical applications of lithium salts may have a potential beneficial effect in countering the effects of superficial applications of these anti-icing and deicing chemicals, but this has not been verified.

6-6 IMPACT OF FLY ASH, SLAG, AND NATURAL POZZOLANS ON OTHER PROPERTIES OF THE CONCRETE MIXTURE.

Generally, these products impart a variety of desirable properties to the concrete mixture; e.g., reduced shrinkage, lowered cost, and lower permeability. However, when used in large quantities, such as for countering ASR, the workability and finishability of the concrete mixture differs appreciably from conventional mixtures. In addition, some of these products require a higher air-entraining dosage to maintain the desired air content. These materials gain strength more slowly than portland cement, but their ultimate strength will be as high or higher.

Strength compliance for concrete pavements can be set at 90 days if operational requirements do not mandate an earlier opening of the pavement to traffic. This will allow additional time for strength gain in these supplementary cementitious materials. In the past, military airfield pavements were accepted based on 90-day strength, but changes in cement chemistry that reduced long-term strength gain and the desire to allow earlier acceptance of the concrete for contractual reasons led many specifications to use 28- or 14-day strengths. With slower-strength-gain materials such as fly ash and ground granulated blast-furnace slag, it is advantageous to allow longer cure periods for strength acceptance when possible.

6-7 ALKALI-CARBONATE REACTION.

Alkali-carbonate reaction is a relatively rare problem and has not arisen in previous military pavement construction. This reaction is significantly different from ASR. Low-alkali cements, fly ashes, and slags are not effective in its control. Fortunately, alkali-carbonate reaction appears to occur only with a few readily identifiable aggregate characteristics. Use petrographic examination specifically to judge if carbonate reaction is a likely problem whenever dolomitic rocks are proposed as aggregate for concrete. If petrographic examination finds potentially reactive alkali-carbonate components in the proposed aggregate, disqualify the aggregate source for use in concrete for military airfields. If no other aggregate sources are reasonably available, consult the Pavements Discipline Working Group (DWG) or their designated representative for more detailed guidance.

APPENDIX A BEST PRACTICES
[RESERVED]

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APPENDIX B GLOSSARY

ºC	degree Celsius
ºF	degree Fahrenheit
AFCEC	Air Force Civil Engineer Center
ASR	alkali-silica reaction
ASTM	American Society for Testing and Materials
BIA	Bilateral Infrastructure Agreement
CaO	calcium oxide
CaO	calcium oxide
CBR	California bearing ratio
CBR	California Bearing Ratio
DoD	Department of Defense
ERDC	Engineering Research and Development Center
ETL	Engineering Technical Letter
FAA	Federal Aviation Administration
FOD	foreign object damage
HNFA	Host Nation Funded Agreement
HQ USACE	Headquarters United States Army Corps of Engineers
IPRF	Innovative Pavement Research Foundation
Na2Oeq	sodium oxide equivalent
NAVFAC	Naval Facilities Command
PCC	portland cement concrete
QA	quality assurance
QC	quality control
RED HORSE	Rapid Engineers Deployable Heavy Operational Repair Squadron Engineer

SME	subject matter expert
SOFA	Status of Forces Agreement
TO	Technical Order
TTP	Tactics, Techniques, and Procedures
U.S.	United States
UFGS	Unified Facilities Guide Specification

APPENDIX C REFERENCES

DOD

http://www.wbdg.org/

UFGS 32 13 14.13 — *Concrete Pavement for Airfields and Other Heavy-Duty Pavements*

TSPWG 3-250-07.07-6 — *Risk Assessment Procedure for Recycling Portland Cement Concrete (PCC) Suffering from Alkali-Silica Reaction (ASR) in Airfield Pavement Structures*

AMERICAN SOCIETY FOR TESTING AND MATERIALS

https://www.astm.org

ASTM C150 — *Standard Specification for Portland Cement*

ASTM C295 — *Standard Guide for Petrographic Examination of Aggregates for Concrete*

ASTM C856 — *Standard Practice for Petrographic Examination of Hardened Concrete*

ASTM C1260 — *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*

ASTM C1293 — *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*

ASTM C1567 — *Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar Bar Method)*

FEDERAL HIGHWAY ADMINISTRATION

https://www.fhwa.dot.gov/resources/pubstats/

RD-03-047 — *Guidelines for the Use of Lithium to Mitigate or Prevent Alkali-Silica Reaction (ASR)*

INNOVATIVE PAVEMENT RESEARCH FOUNDATION

www.iprf.org/products

IPRF-01-G-002-04-8 — *Mitigation of ASR in Presence of Pavement Deicing Chemicals*